Oak Seedling Establishment in Relation to Environmental Factors at Annadel State Park[1]

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Abstract: As part of an ongoing study of oak ecology in Sonoma County, California, we have begun to evaluate various environmental factors relative to oak seedling establishment at Annadel State Park. These factors, identified at three spatial scales (macro, meso and microscales), were corelated with the presence of oak seedlings in two contrasting northern oak woodland understory types - annual and perennial grass. No significant statistical correlations were found, but this is probably due to the small sample size. Preliminary analysis suggests that positive correlations will be found between seedling densities and late spring and summer soil moisture levels maintained by one or more factors at each scale.

This paper is a preliminary report on an ongoing study of oak seedling establishment at Annadel State Park. The objective of the study is to evaluate environments for oak seedling establishment at three spatial scales in order to identify an appropriate scale for making decisions about regeneration projects. A supplementary objective was to see if we could identify environmental factors at different scales which correlate with oak seedling establishment. Management decisions regarding oak planting, restoration of oak woodlands, and the control of grazing livestock to reduce herbivory must be based on an understanding of the relationship between various environmental factors and oak seedling establishment.

The three spatial scales used in this study will be referred to as the macro, meso, and micro scales. The macro-scale is the scale at which plant communities segregate out over the landscape. This scale is determined by local climate, surficial geology, soil types, drainage patterns, land use history, and fire frequency. The mosaic of plant communities in an area is the best expression of the interaction of environmental factors at the macro-scale. Wells (1962) has analyzed the distribution of oak woodlands near San Luis Obispo working at this scale.

The meso-scale environment for seedling establishment is the scale of variation of environmental factors within the boundaries of a plant community. This scale is to a large degree controlled by the modification of environmental factors by the dominant species in the plant community. Environmental factors to be considered at this scale include biotic factors such as tree crown cover, shrub cover, ground cover, and abiotic factors like soil depth, soil moisture, and slope. Analysis of meso-scale factors has been used in many studies of oak seedling establishment (Griffin 1971).

The micro-scale environment for seedling establishment corresponds to the operational environment proposed by Mason and Langenheim (1957). This is the immediate environment surrounding the acorn and developing seedling which impinges directly upon the seedling. Mason and Langenheim saw this operational environment in terms of physical (e.g., heat, atmospheric moisture, etc.) and biotic (e.g., herbivory, pollination, etc.) factors which impinge directly on the physiology and morphology of the plant. We have attempted to characterize the micro-environment in terms of physical and biological conditions we observed in the immediate proximity to seedlings. Such characteristics as distance to nearest object (rock, tree, log), seedling cover by perennial grass leaves and evidence of herbivory and/or drought were used to define the micro-environment of seedlings.

It has occurred to us that the divergent opinions regarding natural seedling establishment in California oaks might be related to differences in the environmental scale at which different investigators approached the study. Muick and Bartolome (1987) working at what we consider the macro-scale suggested that a number of macro-scale factors (e.g., grazing history, precipitation, soil type) are related to variations in seedling establishment. Snow (1972) and McBride (1974) investigated the relationship between some meso-scale factors and seedling establishment in coast live oak (*Quercus agrifolia*). Their work suggests that the degree of crown cover, moisture availability, and livestock grazing in oak woodlands are key factors in seedling establishment. Griffin (1976; 1980) working at what we consider the micro-scale proposed micro-scale factors such as herbivory by pocket gophers as the primary factor controlling seedling establishment.

This paper reports on how a better understanding of oak seedling regeneration may be obtained by properly focusing on the appropriate environmental scale. It was the expectation of this project to identify that scale in the case of Oregon oak (*Quercus garryana*) in Annadel State Park near Santa Rosa, California.

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STUDY AREA

Annadel State Park is located immediately southeast of Santa Rosa, Sonoma County, California, in the Sonoma Mountains. This north-south trending range, primarily composed of Pliocene Sonoma Volcanics above older sediments (Jenkins 1951) is in the eastern portion of the county ca. 30 km from the Pacific coast. Climate patterns are typically Mediterranean with mild winter temperatures (January mean daily minimum 2-3 °C) and hot summer temperatures (July mean daily minimum 28-29°C) which are often moderated by morning fog. Total annual precipitation is ca. 750 mm/year with dry summers and wet winters (January mean 150 mm) (National Oceanographic and Atmospheric Administration 1989).

The vegetation of the park, typical of that found throughout the southern North Coast Range, is a complex mosaic of communities including coastal prairie, chaparral, northern oak woodland, mixed evergreen forest and coniferous forest. The coniferous forest type is most common in the northeastern third of the park. Mixed evergreen forest occurs on northerly slopes and moist drainages throughout the park, integrating with northern oak woodland, particularly in the center of the park. Northern oak woodland is predominant in the southwestern two-thirds of the park, although tree densities and composition vary with aspect. Oregon oak occurs in relatively high densities on north-facing slopes, while south-facing slopes support more open savannas of Oregon oak-blue oak hybrids (*Q. garryana* x *douglasii*). The northern oak woodlands may also be characterized by understory conditions. Perennial grasses dominate the understories of stands on steep, rocky slopes. Northern oak woodlands occurring on less steep slopes and soils without rocks generally support understories of annual grasses. Chaparral occupies relatively small areas throughout the park, usually on southern or western exposures and on rock outcroppings. The prairie type forms small to fairly extensive meadows throughout the park. It is important to note that these vegetation types form a mosaic; areas occupied by a given type are often small and boundaries between types often abrupt.

The area in which Annadel is located was extensively utilized by European settlers and their descendents (Futini 1976). Major types of activities included cattle grazing (intermittent since 1830s), cobblestone quarrying around the turn-of-the-century and extensive cutting of hardwood for cordwood and charcoal in the 1920s. Cattle ranching was the dominant activity from 1930 to 1970. The park was established in 1972.

Several recent studies have focused on the oak woodland and hardwood forest types in Sonoma County with particular reference to Annadel State Park. Anderson and Pasquinelli (1984) described the northern oak woodland at several sites along a moisture gradient within the county, including two sites in Annadel. They concluded that high oak canopy densities and lack of oak regeneration may result in the future dominance of mixed evergreen forest species at the more mesic end of the gradient. Tunison (1973) investigated the distribution of oak woodland and mixed evergreen forest types on Bennett Mountain in Annadel State Park. Noting the dominance of young Douglas-fir (*Pseudotsuga menziesii*) and Bay (*Umbellularia californica*) in the understory of many oak dominated stands, he tentatively concluded that all of these oak types are seral to mixed evergreen forest. Barnhart (1978) suggested a similar vegetation change, although he pointed out that the complex nature of the coast range vegetation makes it difficult to document successional trends. Wainwright and Barbour (1984) demonstrated the diverse nature of the mixed evergreen forest type in Annadel. Barnhart et al. (1987) examined Douglas-fir invasion into the northern oak woodland type at Annadel State Park. They did not, however, report on oak regeneration in these stands.

METHODS

Two oak dominated woodland types were selected for this study as expressions of the macro scale environmental factors at Annadel State Park. These types were the northern oak woodland with perennial grass understory (perennial grass woodland) and the northern oak woodland with annual grass understory (annual grass woodland).

Five 10m by 10m plots were established in September, 1990 at random in each type and the following data were collected:

1. Oak seedlings
   species, number, height, diameter
2. a. Meso-scale factors
   species, diameter at breast height (DBH), and height of trees > 1.4m tall
   - total crown cover on plot
   - pct. ground cover by perennial grass
   - pct. ground cover by annual grass
   - pct. ground cover by litter
   - pct. ground cover by rocks
   - pct. ground cover by logs
   - pct. bare ground
   - litter depth
   - soil depth
   - soil moisture percentage at 0 to 10cm and 20 to 30cm
   - ground slope
   - aspect of plot

   b. Micro-scale factors
   - distance from seedling to nearest rock
   - distance from seedling to nearest tree
   - distance from seedling to nearest clump of perennial grass
   - distance from seedling to nearest log
   - seedling coverage by leaves of perennial grass
   - litter depth at base of seedling
   - evidence of seedling drought
   - evidence of herbivory on seedling

In addition to the micro-scale factors listed above, the distances from 10 points located at random to the nearest rock, tree, clump of perennial grass, and log were measured within each 10m by 10m plot. The litter depth at these random points and the "coverage" of the ground at these points by perennial grass was also recorded.

Data analysis procedures involved comparison, using Student's "t" test, of the average numbers of seedlings found on each vegetation type. Spearman's Rank Correlation was run to establish whether or not the meso-scale variables were correlated with the number of seedlings occurring on the plots. Regressions were initially run for each vegetation type, then the data from both types were combined for a second set of regression analyses. The micro-scale factors occurring at seedlings were compared to the same factors at randomly located points using Student's "t" test and Wilcoxon Rank Sum test.

RESULTS

An average of 23.0 and 11.8 seedlings were found respectively on the perennial grass woodland and the annual grass woodland plots. The majority of these seedlings were Oregon oak; however, hybrids of Oregon oak and blue oak (*Q. douglasii*), California black oak (*Q. kelloggii*), and coast live oak were also present (table l). Seedlings were larger on the plots located in the perennial grass woodland.

Comparison of the average number of oak seedlings observed in each type, using Student's "t" test, showed no significant difference. Similar comparisons between the two vegetation types of the average number of Oregon oak seedlings or hybrid oak seedlings also showed no significant difference. The results of these statistical comparisons are due to the wide range in seedling densities on the plots. Plot number 3 (perennial grass woodland) supported 73 seedlings while plot number 5 had 6 seedlings; the range was from 0 to 24 seedlings on the annual grass woodland plots. We believe this wide range in seedling densities may reflect both local differences in seed production from plot to plot and random variation in seed production from one tree to another. Statistical comparison of average height and average diameter of seedlings likewise showed no significant differences between the perennial and annual grass woodland plots.

Meso-scale Environmental Factors

Average values were calculated for the meso-scale environmental factors measured in this study on five plots within each vegetation type (table 2). None of these averages was significantly correlated with seedling density in either of the oak woodland types. The lack of significant correlation may be due to the small sample size at this preliminary stage in our study. When data from both sets of northern oak woodland plots were combined, Spearman's Rank Correlation Test showed a significant correlation only between the number of seedlings per plot and litter depth.

The lack of a demonstrable correlation between seedlings and crown cover of either trees or perennial grass may be due, in part, to a curvilinear relationship between these two variables, cover and seedling establishment. Spearman's Rank Correlation Test measures the correlation between the independent and dependent variable assuming a linear relationship. The lack of correlation between soil moisture percentage and the number of seedlings may be spurious because of the unusual characteristics of precipitation in spring, 1990. A heavy storm at the end of May brought soil moisture levels back to near field capacity. This precipitation fell after the annual grasses were senescent. This added soil moisture in the annual grass woodlands was slowly

Table 1—*Number, height, and diameter of seedlings on 100m^2 plots to Oregon oak woodlands at Annadel State Park*

Plot Number	Understory Type	Species	Number	Average Height (cm)	Average Diameter (mm)
1	perennial grass	Quga	3	13.6	3.0
		Hybrid	7	13.0	3.0
		Total	10	13.2	3.0
2	"	Quga	3	8.6	2.0
		Hybrid	4	10.0	2.5
		Total	7	9.4	2.2
3	"	Quga	42	12.2	2.6
		Hybrid	30	9.7	2.4
		Quag	1	30.0	10.0
		Total	73	11.0*	2.5*
4	"	Quga	15	21.0	4.0
		Hybrid	4	13.0	3.5
		Total	19	19.4	3.9
5	"	Quga	6	8.5	2.6
		Total	6	8.5	2.6+
Average	"	Quga	13.8	12.8	2.8
		Hybrid	9.0	11.4	2.8
		Quag	0.2	30.0	10.0
		Total	23.0	12.3*	2.8*
6	annual grass	Quga	6	12.5	2.8
		Hybrid	10	9.1	2.3
		Total	16	10.5	2.5
7	"	Total	0	0	0
8	"	Quga	5	8.4	2.4
		Total	5	8.4	2.4
9	"	Hybrid	24	9.6	3.0
		Total	24	9.6	3.0
10	"	Quga	6	10.2	2.2
		Hybrid	8	8.2	2.0
		Total	14	9.0	2.1
Average	"	Quga	3.4	10.1	2.5
		Hybrid	8.4	9.0	2.4
		Total	11.8	9.4	2.5

* Quag height and diameter omitted from calculation of the average
Quga = Quercus garryana
Hybrid = Quercus garryana X douglasii;
Quag = Quercus agrifolia

Table 2—***Average values for Meso-scale environmental factors measured on 100m² Plots in Oregon oak woodland at Annadel State Park***

Environmental Factor	Understory Type Perennial Grass	Annual Grass
1. Number of trees/plot	Value	Value
Quga	6.0	4.6
Hybrid	0.2	0.4
Quke	0.2	0.2
Arma	0.4	0.2
Total	7.0	5.2
2. Tree diameter (cm)		
Quga	22.2	31.5
Hybrid	16.0	31.0
Quke	21.0	22.0
Arma	7.0	13.0
Total	20.6	28.5
3. Tree basal area (m^2)		
Quga	0.252	0.307
Hybrid	0.004	0.033
Quke	0.020	0.008
Arma	0.001	0.002
Total	0.277	0.350
4. Tree crown cover (pct)	57.0	67.0
5. Height of dominant trees (m)	11.8	11.2
6. Perennial grass cover (pct)	60.0	5.1
7. Annual grass cover (pct)	5.0	68.0
8. Litter cover (pct)	16.3	15.0
9. Average log cover (pct)	0.1	0.9
10. Average rock cover (pct)	18.1	9.0
11. Bare ground (pct)	0.0	0.2
12. Litter depth (cm)	3.8	3.1
13. Soil depth (cm)	20.1	18.9
14. September soil moisture (pct)		
10 cm depth	9.2	9.0
30 cm depth	12.1	10.3
15. Slope (pct)	23.2	14.6

Quke = *Quercus kelloggii*
Arma = *Arctostaphylos manzanita*
Quga = *Quercus garryana*
Hybrid = *Quercus garryana X douglasii*

depleted during the ensuing summer months by evaporation and transpiration by the overstory oaks and the oak seedlings. The added spring soil moisture in the perennial grass woodland was depleted during the summer by a combination of evaporation and transpiration, primarily from the perennial grasses. In a normal rainfall year we would anticipate lower soil moisture levels in the annual grass woodland because of the normally early depletion by the annual grasses.

Micro-scale Environmental Factors

Analysis of micro-scale environmental factors was focused on local micro-site factors which were assumed to protect oak seedlings from evaporative stress and from herbivory by deer and pocket gophers. Distances to nearby (within 100cm) objects which might afford protective shade and visual or physical barriers to herbivory were measured for each seedling and for 10 points located at random in each plot. Litter depth adjacent to each seedling and at the random points was also measured as was the percentage of seedlings showing browse damage and drought damage. Results of these measurements are shown in table 3. The distance from random points to the nearest object of any type on the plots which might interfere with deer browsing was less than the distance from seedlings to similar adjacent objects. Comparison of the difference in distances using Student's "t" test and Wilcoxon Rank Sum test showed that the difference in each vegetation type was not significant. A greater number of objects, particularly rocks and perennial grass clumps, occurred in the perennial grass woodland. However, the differences in the distances between nearby objects and random points and the differences in the distances between nearby objects and seedlings were not significant when the two vegetation types were compared. Coverage of seedlings by perennial grass leaves, although greater than coverage of random points, was not significantly different in either vegetation type. Likewise, differences in average litter depths at random points were not significantly different from average litter depths adjacent to seedlings. Drought damage was lower in annual grass woodlands than in perennial grass woodlands. Browse damage was greater on plots in the annual grass type. Differences, however, were not significant.

CONCLUSIONS

The lack of any statistical correlation between environmental factors at either the macro, meso, or micro-scale is, we believe, a function of the small sample size available for analysis

Table 3—***Micro-scale environmental factors measured on 100m² plots in Oregon oak woodlands at Annadel State Park***

	Understory Type			
	Perennial Grass		Annual Grass	
Environmental Factor	Oak Seedling	Random Point	Oak Seedling	Random Point
1. Average distance (cm) to nearest				
rock	60.6	57.5	92.2	80.7
perennial grass clump	21.5	18.8	71.4	93.2
log	94.7	97.6	86.9	93.2
tree	95.6	97.6	85.0	97.7
object (rock, perennial grass, etc.)	17.3	14.7	58.2	55.4
2. Coverage by perennial grass leaves (pct)	86.4	50.4	6.6	2.0
3. Litter depth (cm)	3.8	3.8	3.1	3.1
4. Drought damage seedlings (pct)	44.3	—	17.5	—
5. Browsed damaged seedlings (pct)	57.4	—	80.0	—

at this time in our study. The variability between plots will most likely be reduced as the number of samples increases. We are convinced from our field observations at Annadel State Park that relationships do exist between seedling establishment and some environmental factors at each of the three spatial scales used in this study.

At the macro-scale we anticipate that an increased sample size will confirm a significant difference between the numbers and sizes of oak seedlings observed on the two northern oak woodland types. The larger number of seedlings and their larger size (height and diameter) suggested by the average number and average seedling size on the perennial grass woodland plots is, we believe, a function of the macro-scale environmental factors which distinguish the northern oak woodland types. We believe these factors to be soil type and aspect, both of which influence water availability to oak seedlings.

Meso-scale environmental factors which we anticipate will show a significant correlation with seedling establishment are soil moisture, rock cover, and litter cover. In a typical rainfall year we should anticipate higher soil moisture in perennial grass woodlands. The unusual pattern of late spring precipitation in 1990 accounts for a leveling of the differences in soil moisture both between the two vegetation types and among plots of each vegetation type. We believe that higher soil moisture levels at the end of the growing season will correlate with greater numbers of oak seedlings.

With increased sample size, the percentage of rock cover should show a significant correlation with seedling density and survival in perennial grass woodlands. Rock cover is significant because it facilitates increased soil moisture due to run-off from the impervious surfaces to the surrounding soil. Rock cover also reduces soil moisture loss due to evaporation, since soil beneath the rocks is protected from solar radiation, thus providing pockets of available moisture later into the growing season. Rocks below ground serve as condensation surfaces for water vapor in the soil, thus concentrating soil moisture near their boundary with the soil. The presence of rocks on the ground may reduce the use of an area by deer.

Percentage of the ground covered by litter should also be shown to correlate with seedling numbers as our sample size increases. We believe that litter cover is significant because it protects acorns from predation and desiccation prior to germination and it reduces evaporation of moisture from the soil. It also is a measure of the area of ground that is not occupied by plants, and therefore under reduced loss of soil moisture to transpiration.

At the micro-scale of environmental factors a larger sample size is not expected to change our observation, based on the current data, that objects such as rocks, logs, or perennial grass leaves protect oak seedlings from herbivory. In both woodland types, the distances from random points to nearby objects were closer than the distance from seedlings to the nearest object. Although the trends in herbivory were greater on annual grass woodland plots, where protective objects occurred less frequently, we do not think that more data will demonstrate the protective effect of nearby objects. The evidence of herbivory we observed was assumed to be the result of deer browsing. This may not be the case. Smaller herbivores, less affected by nearby objects, may be responsible for the herbivory we recorded. If, however, deer are responsible for the observed browsing, their behavior may be more influenced by vegetation type than nearby objects.

Data from the current plots showed a trend toward greater drought injury to seedlings in oak woodlands with perennial grass understories. We think this trend is the result of the unusual pattern of late spring precipitation in 1990 and is not typical. The resulting additional moisture available to oak seedlings on plots with annual grass understories minimized drought injury to the seedlings on these plots. Competition for soil moisture between the perennial grasses and oak seedlings following the late spring rain may account for the trend in greater drought injury to seedlings on the plots with perennial grass understories.

The data base available at this point in our study is insufficient to make conclusions concerning the relative value of the three scales of environmental factor analysis. We look forward to an elucidation of this question when a greater data base is assembled.

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